10/19/01 CD
11/29/01 CD
7/12/02 CD
03/14/03 CD
3/27/03 CD

Issue Paper –
Total Dissolved Solids (TDS)

I. Background

The TDS is a measure of all constituents dissolved in water. The principal inorganic anions dissolved in water include carbonates, chlorides, sulfates and nitrates. The principal cations are sodium, potassium, calcium and magnesium.

The current Iowa water quality standard for Total Dissolved Solid (TSD) was developed in the 70's and is stated in IAC [567] Chapter 61.3(2)g *General water quality criteria* as follows:

"Total dissolved solids shall not exceed 750 mg/l in any lake or impoundment or in any stream with a flow rate equal to or greater than three times the flow rate of upstream point source discharges."

Several NPDES permittees have noted that Iowa's long standing Total Dissolved Solids (TDS) numerical criteria of 750 mg/l is inconsistent with current toxicity information. This criterion is listed as one of the General Water Quality Criteria that are applicable to all waters. Data that provided by a Permittee indicates that warm water aquatic species are tolerant of a more relaxed TDS level.

The triennial review of the TDS criteria would address the issue and also include the implementation methodology for wasteload allocations.

II. Site-Specific Toxicity Data for TDS

IPSCO Steel Inc. provided the toxicity testing for Fathead minnow (*Pimephales promelas)* and Ceriodaphnia (*Ceriodaphnia dubia)* to IDNR on March 14, 1996. The facility was planning to collect the treated process wastewater and storm water in a detention pond and then discharge into Comrie Creek, a tributary of the Mississippi River. In order to determine the maximum level of effluent TDS that would potentially be acceptable from an aquatic acute toxicity standpoint, acute toxicity tests were conducted. Since the facility was under construction during that time and no wastewater was being generated, a simulated effluent from the process wastewater systems in conformance with the guidelines established by the IDNR standard Operating Procedure for Effluent Toxicity Testing was used. A 48-hour toxicity testing on the indicator species were conducted. The acute toxicity testing indicated that the LC50 response level to the TDS for Fathead minnow is between 5000 mg/l and 7000 mg/l. The LC50 response level to the TDS for Ceriodaphnia was between 2500 mg/l and 3000 mg/l.

III. TDS Information from Different Sources

All species of fish and other aquatic life must tolerate a range of dissolved solids concentrations in order to survive under natural conditions. According to the redbook of EPA (Quality Criteria for Water, 1976), studies have shown that lakes with dissolved solids in excess of 15,000 mg/l were unsuitable for most freshwater fishes.

It has also been reported that for livestock, 3000 mg/l of TDS should be satisfactory for animal consumption under most circumstances.

The report that IPSCO Steel Inc. submitted to IDNR included some TDS testing information on different freshwater fishes and other organisms. Table 1 presents the information on certain species that also present in Iowa streams.

Table 1. Toxicity Test Data on Certain Species based on Literature

Organisms	**Concentration (mg/L)**	**Reported Effect**
Daphnia magna	9,500-11,500	96-hr LC50
Hyalella azteca	11,500	96-hr LC50
Bigmouth buffalo Emerging fry	9,000	Upper tolerance limit
Black buffalo Emerging fry	9,000	Upper tolerance limit
Channel catfish	14,000	Upper tolerance limit
Black bullhead	8,000 10,000	Median toxicity threshold in NaCl Probable lethal limit
Yellow perch	11,500	No adverse effects
Fathead minnow	6,000-7,000 5,300-5,900	Acutely lethal 96-hr LC50
Green Sunfish	10,700 20,000	Median toxicity threshold in NaCl Lethal
Bluegill	11,900	Lethal limit
Golden Shiner	5,600	Upper tolerance limit
Common Carp	12,000 18,500-19,000	No observed effect Upper tolerance limit
Beef cattle	10,000	Safe upper limit
Dairy cattle	7,150	Safe upper limit
Poultry	2,860	Safe upper limit

IV. TDS Criteria in Other States

1. Kansas

(1) Domestic Water Supply:

Chloride – 250 mg/l
Sulfate – 250 mg/l

(2) Aquatic Life Use:

Chloride – 860 mg/l (Acute)

(3) Agricultural Livestock Use:
Sulfate – 1000 mg/l

2. Missouri

(1) Drinking Water Use:

Chloride – 250 mg/l
Sulfate – 250 mg/l

(2) Protection of Aquatic Life:

Chloride – 860 mg/l (Acute), 230 mg/l (Chronic)

3. Nebraska

(1) Drinking Water Use

Chloride: 250 mg/l
Sulfate: 250 mg/l
TDS: 500 mg/l

(2) Agricultural Use

Conductivity: 2,000 μmho/cm between April 1 and September 30 (equivalent to TDS of 1280 – 1400 mg/l).
NO3 and NO2 as Nitrogen: not to exceed 100 mg/l
Selenium: not to exceed 0.02 mg/l

3. Illinois

(1) General Water Quality Standards:

Chloride – 500 mg/l
Sulfate – 500 mg/l
TDS – 1000 mg/l

(2) Public and Food Processing Water Supply Standards

Chloride – 250 mg/l
Sulfate – 250 mg/l
TDS – 500 mg/l

(3) Secondary Contact and Indigenous Aquatic Life Standards:

TDS – 1500 mg/l.

4. State of Pennsylvania

For Public Water Supply use, the TDS, chloride and sulfate water quality standards are:

Parameters	Monthly Average	Daily Maximum
TDS	500	750
Chloride	-	250
Sulfate	-	250

These standards **only** apply to public water supply uses.

Most States have a TDS criterion of 500 mg/l for domestic drinking water supply, and chloride and sulfate range from 200 to 250 mg/l for domestic water supply. For aquatic life, the values range from 250 mg/l to 2500 mg/l. Some states limit the TDS concentration not exceeding 133% of ambient stream concentration. Some States do not have any specific numeric criteria for TDS.

V. Discussion of TDS as a Water Quality Parameter

Some studies (Mount et al., 1997) indicated that aquatic organisms respond differently to different TDS compositions. Mount et al. (1997) also demonstrated that relative ion toxicity was in the order of $K^+ > HCO_3^- \approx Mg^{2+} > Cl^- > SO_4^{2-}$. EPA's chloride criteria document (1988) indicated that when compared on the basis of chloride, the chlorides of potassium, calcium, and magnesium are generally more acutely toxic to aquatic animals than sodium chloride. Thus, the toxicity of TDS may vary depending on the specific constituent compositions of the TDS in the effluent. The same problems would relate to the effects of TDS on livestock. However, there is still a lack of sufficient research data required to quantify the potential effects of all the different constituents of TDS.

VI. Agricultural Uses: TDS and Individual Ions

A. Livestock Watering

Both the US and Canada have developed "Guides to the Use of Saline Waters for Livestock Watering." The Canadian Task Force on Water Quality (1987) published both a Summary – Guidelines for Livestock Drinking Water Quality and a Guide to Use of Saline Water for Livestock Watering. They are listed as follows:

Table 2. Summary – Guidelines for Livestock Drinking Water Quality

Parameter	Guidelines (mg/l)
Major Ions and Nutrients	
Calcium	1000
Nitrate plus nitrite	100
Nitrite alone	10
Sulfate	1000
TDS	3000

The National Academy of Sciences (1974) published a Guide to the Use of Saline Waters for Livestock and Poultry. It states that "if the TDS is between 1000 – 2999 mg/l, the waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry, but should not affect their health or performance."

The web site of "Manitoba Agriculture and Food" pointed out an upper limit of 300 – 400 mg/l of magnesium has been suggested for dairy cows. For sodium, water with over 800 mg sodium/l can cause diarrhea and a drop in milk production in dairy cows.

The EPA's "Quality Criteria for Water" (1976) stated that chickens, swine, cattle, and sheep can survive on saline waters up to 15,000 mg/l salts of sodium and calcium combined with bicarbonates, chlorides, and sulfates but only 10,000 mg/l of corresponding salts of potassium and magnesium. The approximate limit for highly alkaline waters containing sodium and calcium carbonates is 5,000 mg/l.

Rodenburg (1989) indicated that routine water analysis for livestock use should include TDS, sodium, magnesium, calcium, sulfate, nitrate, iron and pH. Rodenburg (1989) also pointed out that studies demonstrate that magnesium, sodium, and sulfate are toxic at lower levels than calcium, chloride or bicarbonate, and that there will be highly variable response to water of 1000 to 5000 mg/l TDS, depending on which ions dominate. He provided the water quality criteria for dairy cattle. The following table lists the major ion criteria for dairy cattle based on Rodenburg (1989).

Table 3. Water Quality Criteria for Dairy Cattle

Ions	Max. Recommended Concentration (mg/l)
Sulfate	1000
Magnesium	800
Sodium	800
Calcium (dry cows & growing bulls)	1000
Calcium (milking cows & heifers)	2000
Nitrate-N	100

Most of the studies on TDS are based on sodium chloride constituent. Different studies recommended different safe values of sodium chloride for livestock uses. The National Academy of Sciences (1974) reported the safe sodium chloride value for cattle as 10,000 mg/l. And Jaster et al (1978) reported that the safe sodium chloride value for dairy cows were 2500 – 3500 mg/l. Some studies indicated that for poultry the safe sodium chloride value was 3000 mg/l.

To summarize the status of the current studies of TDS toxicity on aquatic life and livestock, it is recognized that the toxicity of TDS may vary depending on the specific constituent compositions of the TDS in the effluent. However, there are a lot of uncertainties about the potential effects of all the different constituents of TDS. Based on limited studies on TDS and the individual ions, the following water quality criteria should meet the livestock uses.

Table 4. Recommended Water Quality Criteria for Livestock Uses

Ions	Recommended Criteria for Livestock Uses (mg/l)
Calcium	1000
Magnesium	800
Sodium	800
Sulfate	1000
Nitrate+Nitrite-N	100

B. Irrigation Water Uses

Peterson (1999) pointed out that TDS levels below 700 mg/l are considered safe; TDS between 700 mg/l and 1,750 mg/l are considered possibly safe, while levels above these levels are considered hazardous to any crop. Peterson (1999) also listed the tolerance of selected crops to TDS in irrigation water, for example, corn as *slightly tolerant* (TDS < 800 mg/l) and soybean as *very tolerant* (TDS < 3500 mg/l). However, as long as the TDS concentration is less than 2,800 mg/l, no reduction in crop yield for moderately sensitive crops including corns and soybeans (Peterson, 1999). Generally forage crops are the most resistant to salinity, followed by field crops, vegetable crops, and fruit crops which are generally the most sensitive.

Irrigation water containing large amounts of sodium is of special concern due to sodium's effects on the soil structure. Crops grown on soil having an imbalance of calcium and magnesium may also exhibit toxic symptoms. Sulfate salts affect sensitive crops by limiting the uptake of calcium and increasing the adsorption of sodium and potassium, resulting in a disturbance in the cationic balance within the plant. The bicarbonate ion in soil solution harms the mineral nutrition of the plant through its effects on the uptake and metabolism of nutrients. High concentrations of potassium may introduce a magnesium deficiency and iron chlorosis. An imbalance of magnesium may be toxic, but the effects of both can be reduced by high calcium levels. The Surface Water Quality Objectives published by Saskatchewan Environment and Resource Management in August 1997 listed corn as one of the *moderately tolerant* plant to sodium and chloride. The tolerance concentration to chloride and sodium in irrigation water for corns are Chloride (335 – 710mg/l) and Sodium (230 – 460mg/l). Also, Mills (2001) provided the following toxicity values for chloride, iron and NO3 to plants.

Table 5. Toxicity Data for Chloride, Iron and NO3 in Irrigation water

Chloride Ion Conc.	Suitability for Irrigation
< 350 mg/l	Suitable all crops
350 – 700 mg/l	Suitable for high, medium and low salt tolerant crops
700 – 900 mg/l	Suitable for high and medium salt tolerance crops
900 – 1300 mg/l	Suitable for high salt tolerant crops only.
Greater than 1300 mg/l	Too saline for irrigation of any crops
Iron	< 1 mg/l
NO3	<133 mg/l

Since corn is *moderately tolerant* to chloride, it should be able to tolerate 700 – 900 mg/l of chloride concentration. Some studies have shown that for surface irrigation, most tree crops and woody plants are sensitive to sodium and chloride, while most annual crops are not sensitive ("Water Quality and Crop Production").

To summarize the water quality requirement for irrigation uses, the following criteria should apply:

Table 6. Water Quality Criteria for Irrigation Uses

Ions	Criteria for Irrigation Uses (mg/l)
Chloride	900
NO3	<133 mg/l

However, at the Technical Advisory Committee meeting on March 21, 2003, the committee members agreed to drop the chloride value of 900 mg/l for irrigation uses at this time because of lack of sufficient information. The IDNR and the committee could visit the issue later when new information becomes available.

VI. Proposed Ion Criteria for Iowa

Based on the literature review and the recommendations by WQS Technical Advisory Committee, the Department proposes the following ion criteria and approach for the protection of both the agricultural use and the aquatic life use.

1. Protection of Agricultural Uses

(1) Ion Criteria Values

Table 7. Recommended Water Quality Criteria for Agricultural Uses

Ions	Recommended Criteria for Livestock Uses (mg/l)
Calcium	1000
Magnesium	800
Sodium	800
Sulfate	1000
Nitrate+Nitrite-N	100

On March 21, 2003, the TAC members agreed that the above ion criteria values should be included in the Support Document for implementation since these numbers are based on guidelines for livestock uses not criteria-based toxicity tests.

(2) Implementation

The ion criteria values shown in Table 7 should be applied at the end-of-pipe in general use waters, and at the end of the mixing zone in designated waters.

2. Protection of Aquatic Life Uses

The Technical Advisory Committee on the March 21th meeting agreed that in order to protect the aquatic life uses, Whole Effluent Toxicity (WET) test of TDS is required **whenever the facility requests for a permit renewal every five years**. The facility also needs to measure the ion constituents in the effluent at the same time. The following table lists the parameters need to be included in the specific ion constituent test.

Table 8. Ion Constituents Tested in the WET Test

Ions
TDS
Calcium
Potassium
Magnesium
Sodium
Sulfate
Ion
Nitrate+Nitrite-N

If the effluent discharges into a general use stream, 100% of the effluent should be used in the WET test. If the effluent discharges directly into a designated stream, a 2.5% of the stream 7Q10 flow is allowed for dilution in the WET test. The WET test should follow the EPA published manual of "*Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms*" adopted as final rule on November 19, 2002. And the WET test should be performed for two freshwater organisms: *fathead minnows* and *Ceriodaphnia dubia*.

In conclusion, all Waters of the State should meet the above requirements to protect both the agricultural and aquatic life uses.

VIII. Proposed Rule Changes: reserved for future.

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Appendix A: Ion Concentration Comparison
(surface water vs. groundwater vs. industrial discharge)

Table A1. Surface and Groundwater Ion Concentrations

	Groundwater (70 stations-2000 water year)	Des Moines R. at Des Moines	Missouri R. @ Omaha	Mississippi River@ Clinton	WAPSIPINICON River@ TRIPOLI	IOWA River@Rc
TDS	555	422	522.9	230.6	249	411.8
Hardness as CaCo3	356		270	163.	--	--
Ca	89	77.2	66.3	38.9	51.0	83.6
Mg	29	27.8	25.4	15.7	11.7	26.5
K	4	2.8	7.0	2.61	2.0	2.6
Na	32	17.8	55.7	9.15	9.7	9.5
CO3 as CaCo3	--	--	1.0	1.00	0	0.6
HCO3 as CaCo3	--	--	199.3	170.	155	282
Chloride	22	33.2	14.8	13.98	21.4	19.9
Sulfate	106	77.5	197.6	25.92	21.5	42.3
NO3	5	7.5	1.5	1.80	5.3	7.1

The following shows a few sample industrial discharge characteristics:

Table A2. ADM – Des Moines Discharge Characteristics

		Effluent	Des Moines River
Parameter	Month	Concentration (mg/l)	Concentration (mg/l)
TDS	9/02	443	400
	8/02	544	380
	7/02	645	380
	6/02	593	400
	5/02	322	390
	4/02	418	480
	3/02	705	470
	2/02	716	540
	1/02	640	550
	12/01	464	380
	11/01	420	340
	10/01	334	350

Table A3. Siouxland Ethanol Facility, Sioux Center, Sioux County, IA

Parameters	Raw Groundwater	RO Reject Water	Surface Water (Tributary)
TDS	2113	7288	703 (Big Sioux data)
Ca	305	1033	129
Mg	138	458	58
K	0	0	1.5
Na	148	485	20

Cl	23	131	35
SO4	1420	4716	107
NO3	10	30	128
HCO3	155	412	NA

Table A4. Midwest Grain Processors in Kossuth County

Parameters	Groundwater Source (mg/l)	Tower Blowdown Effluent
TDS	878	3020
Ca		136
Mg		194
K		0
Na		222
Iron		0.588
Cl		14.6
SO4		1510

Table A5. Little Sioux Ethanol: Simulated Blowdown

Parameters	Tower Blowdown Effluent
TDS	3240 as CaCO3
Ca	637.5
Mg	184.8
K	32.5
Na	297
Iron	1.3
Cl	26.9
SO4	2265